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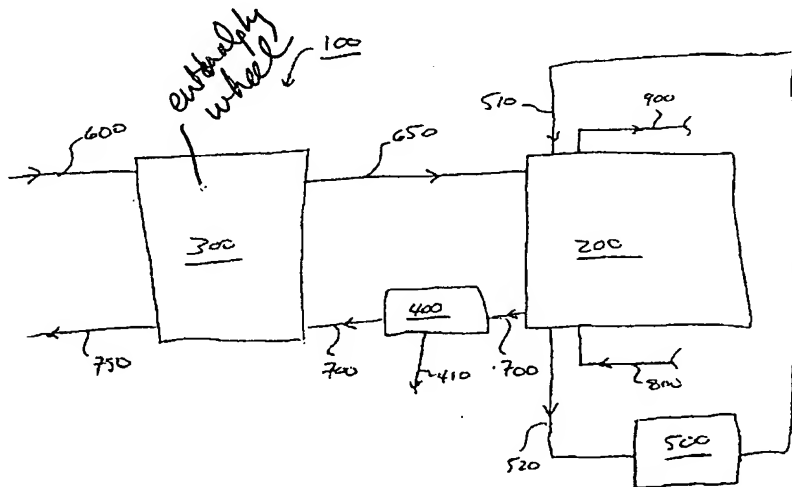
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(54) Title: ENTHALPY RECOVERY FUEL CELL SYSTEM



(57) Abstract: The invention relates to an enthalpy recovery fuel cell system (100). Water leaving the fuel cell in the cathode gas output stream (700) is transferred to the cathode gas input stream (650) via an enthalpy wheel (300). The dew point of the input stream of the cathode gas is about the same as the temperature of the leading edge of the active area of the solid electrolyte, such as a proton exchange membrane. The temperature differential across the fuel cell is about the same as the difference in the dew points of the cathode gas entering the fuel cell and the cathode gas exiting the fuel cell.

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Enthalpy Recovery Fuel Cell System

The invention relates to an enthalpy recovery fuel
5 cell system.

Background of the Invention

A fuel cell can convert chemical energy to
electrical energy by promoting a chemical reaction between
two reactant gases.

10 One type of fuel cell includes a cathode flow field
plate, an anode flow field plate, a membrane electrode
assembly disposed between the cathode flow field plate and
the anode flow field plate, and two gas diffusion layers
15 disposed between the cathode flow field plate and the anode
flow field plate. A fuel cell can also include one or more
coolant flow field plates disposed adjacent the exterior of
the anode flow field plate and/or the exterior of the
cathode flow field plate.

Each reactant flow field plate has an inlet region,
20 an outlet region and open-faced channels connecting the
inlet region to the outlet region and providing a way for
distributing the reactant gases to the membrane electrode
assembly.

The membrane electrode assembly usually includes a
25 solid electrolyte (e.g., a proton exchange membrane) between
a first catalyst and a second catalyst. One gas diffusion
layer is between the first catalyst and the anode flow field
plate, and the other gas diffusion layer is between the
second catalyst and the cathode flow field plate.

30 During operation of the fuel cell, one of the
reactant gases (the anode reactant gas) enters the anode
flow field plate at the inlet region of the anode flow field
plate and flows through the channels of the anode flow field
35 plate toward the outlet region of the anode flow field
plate. The other reactant gas (the cathode reactant gas)

enters the cathode flow field plate at the inlet region of the cathode flow field plate and flows through the channels of the cathode flow field plate toward the cathode flow field plate outlet region.

5 As the anode reactant gas flows through the channels of the anode flow field plate, some of the anode reactant gas passes through the anode gas diffusion layer and interacts with the anode catalyst. Similarly, as the cathode reactant gas flows through the channels of the
10 cathode flow field plate, some of the cathode reactant gas passes through the cathode gas diffusion layer and interacts with the cathode catalyst.

 The anode catalyst interacts with the anode reactant gas to catalyze the conversion of the anode reactant gas to
15 reaction intermediates. The reaction intermediates include ions and electrons. The cathode catalyst interacts with the cathode reactant gas and the reaction intermediates to catalyze the conversion of the cathode reactant gas to the chemical product of the fuel cell reaction.

20 The chemical product of the fuel cell reaction flows through a gas diffusion layer to the channels of a flow field plate (e.g., the cathode flow field plate). The chemical product then flows along the channels of the flow field plate toward the outlet region of the flow field
25 plate.

 The electrolyte provides a barrier to the flow of the electrons and reactant gases from one side of the membrane electrode assembly to the other side of the membrane electrode assembly. However, the electrolyte
30 allows ionic reaction intermediates to flow from the anode side of the membrane electrode assembly to the cathode side of the membrane electrode assembly.

Therefore, the ionic reaction intermediates can flow from the anode side of the membrane electrode assembly to the cathode side of the membrane electrode assembly without exiting the fuel cell. In contrast, the electrons flow from the anode side of the membrane electrode assembly to the cathode side of the membrane electrode assembly by electrically connecting an external load between the anode flow field plate and the cathode flow field plate. The external load allows the electrons to flow from the anode side of the membrane electrode assembly, through the anode flow field plate, through the load and to the cathode flow field plate.

Because electrons are formed at the anode side of the membrane electrode assembly, that means the anode reactant gas undergoes oxidation during the fuel cell reaction. Because electrons are consumed at the cathode side of the membrane electrode assembly, that means the cathode reactant gas undergoes reduction during the fuel cell reaction.

For example, when molecular hydrogen and molecular oxygen are the reactant gases used in a fuel cell, the molecular hydrogen flows through the anode flow field plate and undergoes oxidation. The molecular oxygen flows through the cathode flow field plate and undergoes reduction. The specific reactions that occur in the fuel cell are represented in equations 1-3.



As shown in equation 1, the molecular hydrogen forms protons (H^+) and electrons. The protons flow through the

electrolyte to the cathode side of the membrane electrode assembly, and the electrons flow from the anode side of the membrane electrode assembly to the cathode side of the membrane electrode assembly through the external load. As
5 shown in equation 2, the electrons and protons react with the molecular oxygen to form water. Equation 3 shows the overall fuel cell reaction.

In addition to forming chemical products, the fuel cell reaction produces heat. One or more coolant flow field
10 plates are typically used to conduct the heat away from the fuel cell and prevent it from overheating.

Each coolant flow field plate has an inlet region, an outlet region and channels that provide fluid communication between the coolant flow field plate inlet
15 region and the coolant flow field plate outlet region. A coolant (e.g., liquid de-ionized water) at a relatively low temperature enters the coolant flow field plate at the inlet region, flows through the channels of the coolant flow field plate toward the outlet region of the coolant flow field
20 plate, and exits the coolant flow field plate at the outlet region of the coolant flow field plate. As the coolant flows through the channels of the coolant flow field plate, the coolant absorbs heat formed in the fuel cell. When the coolant exits the coolant flow field plate, the heat
25 absorbed by the coolant is removed from the fuel cell.

To increase the electrical energy available, a plurality of fuel cells can be arranged in series to form a fuel cell stack. Typically, in a fuel cell stack, one side of a flow field plate functions as the anode flow field
30 plate for one fuel cell while the opposite side of the flow field plate functions as the cathode flow field plate in another fuel cell. This arrangement of anode/cathode flow field plates is repeated to provide the reactant flow field

plates of the fuel cell stack. The fuel cell stack can further include coolant flow field plates interspersed between the anode and cathode flow field plates.

Summary of the Invention

5 The invention relates to an enthalpy recovery fuel cell system.

 The fuel cell system is designed so that water vapor leaving the fuel cell in the cathode gas (e.g., oxidant gas) output stream is transferred to the cathode gas input
10 stream. This can decrease the amount of water that is added to the fuel cell system from an external source relative to an otherwise substantially identical fuel cell system having a design in which the water vapor contained in the cathode gas output stream is not transferred to the cathode gas
15 input stream.

 The fuel cell system is also designed so that the dew point of the cathode gas input stream is greater than or about the same as the temperature of the leading edge of the active area of the solid electrolyte (i.e., the first edge
20 of the active area of the solid electrolyte intersected by the cathode gas as it flows through the fuel cell). This can reduce the tendency of the solid electrolyte to dry out at the leading edge of the active area of the fuel cell relative to an otherwise substantially identical fuel cell
25 system having a design in which the dew point of the input cathode gas just prior to entering the fuel cell is less than the temperature of the leading edge of the active region of the fuel cell.

 In addition, the system can be designed so that the
30 temperature differential across the fuel cell matches the difference between the dew point of the cathode gas input stream and the dew point of the cathode gas output stream (e.g., by using a coolant system which controls the mass

flow rate and/or temperature of coolant flowing through the fuel cell). This matching increases the efficiency of water transfer from the cathode gas output stream to the cathode gas input stream relative to a fuel cell system having an otherwise substantially identical design in which the dew point differential between the cathode gas just before it enters the fuel cell and the cathode gas just after it exits the fuel cell is not about the same as the temperature differential across the active area of the fuel cell.

Other advantages, such as increased fuel cell system efficiency, can be achieved according to different embodiments of the invention.

In general, one aspect of the invention is a fuel cell system which includes a fuel cell and an enthalpy recovery device. The fuel cell includes a cathode flow field plate, an anode flow field plate, a coolant flow field plate and a solid electrolyte between the cathode and anode flow field plates. The cathode flow field plate has an inlet, an outlet, and a flow path from its inlet to its outlet. The coolant flow field plate also has an inlet, an outlet, and a flow path from its inlet to its outlet. The solid electrolyte has an active area. The cathode flow field plate flow path has a first region which corresponds to the region along the cathode flow field plate flow path that is closest to the cathode flow field plate inlet and that intersects (i.e., projects onto) the solid electrolyte active area. The coolant flow field plate flow path also has a first region which corresponds to the region along the coolant flow field plate flow path that is closest to the coolant flow field plate inlet and that intersects the solid electrolyte active area. The first region of the cathode flow field plate flow path is substantially the same as the first region of the coolant flow field plate flow path. The

enthalpy recovery device has a first side in fluid communication with the cathode flow field plate outlet, and a second side in fluid communication with the cathode flow field plate inlet.

- 5 The fuel cell system can also include a first catalyst between the cathode flow field plate and the solid electrolyte, a second catalyst between the anode flow field plate and the solid electrolyte, a first gas diffusion layer between the first catalyst and the cathode flow field plate,
10 and a second gas diffusion layer between the second catalyst and the anode flow field plate.

- The fuel cell device can further include a coolant system including a feedback device, a variable speed pump and/or a variable speed fan. The pump outlet is in fluid
15 communication with the coolant flow field plate inlet, and the pump inlet is in fluid communication with the coolant flow field plate outlet. The coolant system can further include temperature sensors in electrical communication with the feedback device to monitor the inlet and outlet
20 temperatures of a coolant flowing along the coolant flow path and of a reactant gas flowing along the cathode flow field plate flow path, and to adjust the pump speed and/or the fan speed to adjust the inlet and outlet temperatures of the coolant. In this manner, the feedback device can set
25 the temperature of the coolant at the coolant flow field plate inlet and the coolant flow field plate outlet so that the difference between these temperatures is about the same as the difference between the dew points of the cathode gas (e.g., oxidant gas) entering the fuel cell and the cathode
30 gas (e.g., oxidant gas) exiting the fuel cell.

 The fuel cell system can also include a liquid water separator with an inlet that is in fluid communication with the cathode flow field plate outlet and an outlet that is in

fluid communication with the first side of the enthalpy recovery device. The liquid water separator includes an additional outlet through which liquid water can be removed from the cathode gas exiting the fuel cell.

- 5 The net flow direction of the cathode flow field plate flow path can be in a direction that is opposite (antiparallel) to the net flow direction of the anode flow field plate flow path (i.e., countercurrent flow between the cathode gas and the anode gas). The coolant flow field
10 plate flow path can be generally parallel to the cathode flow field plate flow path (i.e., concurrent flow between the cathode gas and the coolant).

- In general, another aspect of the invention is a method of operating a fuel cell system. The method includes
15 introducing an oxidant gas stream and a coolant stream into the fuel cell. Upon introduction into the fuel cell, the dew point of the oxidant gas stream is greater than or about the same as the temperature of the coolant stream. The method also includes flowing the oxidant gas stream through
20 the fuel cell along a flow path to an oxidant gas stream outlet, and flowing the coolant stream through the fuel cell along a different flow path. The method further includes reacting molecular oxygen contained in the oxidant gas stream with molecular hydrogen in the fuel cell to form a
25 humidified oxidant gas output stream. In addition, the method includes outputting the humidified oxidant gas output stream from the oxidant gas stream outlet, and transferring water vapor from the humidified oxidant gas output stream to a dry oxidant gas stream to form a humidified oxidant gas
30 input stream.

 In general, a further aspect of the invention is a method of operating a fuel cell system which includes a fuel cell having a solid electrolyte with an active area. The

method includes flowing an oxidant gas stream through the fuel cell along a flow path which has a first region that intersects the solid electrolyte active area at a region closest to a cathode inlet along the cathode flow path. The method also includes flowing a coolant through the fuel cell along a different flow path which has a first region that intersects the solid electrolyte active area at a region closest to the coolant inlet along a coolant flow path. The temperature of the coolant at the first region of the coolant flow path is less than or about the same as the dew point of the oxidant gas stream at the first region of the oxidant gas stream flow path. The method further includes outputting the oxidant gas stream from the fuel cell, transferring water vapor from the oxidant gas output stream to a dry oxidant gas stream to form a humidified oxidant gas stream input stream.

Other advantages and features will become apparent from the following description of the preferred embodiments and the claims.

Brief Description of the Drawings

Fig. 1 is a block diagram of a fuel cell system according to an embodiment of the invention;

Fig. 2 is a cross-sectional view of a fuel cell according to an embodiment of the invention;

Fig. 3 is an elevational view of a solid electrolyte according to an embodiment of the invention;

Fig. 4 is an elevational view of a cathode flow field plate according to an embodiment of the invention;

Fig. 5 is an elevational view of an anode flow field plate according to an embodiment of the invention; and

Fig. 6 is an elevational view of a coolant flow field plate according to an embodiment of the invention

Fig. 7 is a block diagram of a coolant system according to an embodiment of the invention.

Detailed Description

Fig. 1 shows an embodiment of the invention in which
5 a fuel cell system 100 includes a fuel cell 200, an enthalpy wheel 300, a liquid water separator 400 with a liquid outlet 410, and a coolant system 500 having a coolant stream inlet 510 and a coolant stream outlet 520. Fuel cell system 100 also includes a dry oxidant gas input stream 600, a
10 humidified oxidant gas input stream 650, a humidified oxidant gas output stream 700, a dry oxidant gas output stream 750, a fuel gas input stream 800 and a fuel gas output stream 900.

During operation of fuel cell 200, molecular
15 hydrogen and molecular oxygen contained in streams 800 and 650, respectively, flow through fuel cell 200 and react to produce electricity, heat and water. The water produced during the fuel cell reaction is removed from fuel cell 200 in streams 700 and 900 in the form of water vapor and liquid
20 water.

The liquid water contained in stream 700 is removed by passing the stream through liquid separator 400. In one embodiment, liquid separator 400 is a vessel. Generally, the vessel operates by reducing the velocity of the flow
25 rate of stream 700 to allow for gravity separation of the liquids and gases contained in stream 700. Liquid water can exit separator 400 via outlet 410, while gas stream 700 can continue to enthalpy wheel 300. Other examples of liquid separators include centrifugal separators and wicking
30 separators.

Water vapor contained in stream 700 is removed by flowing the stream through enthalpy wheel 300 which transfers water vapor from stream 700, which has a

relatively high dew point, to stream 600, which has a relatively low dew point. The water transfer from stream 700 to stream 600 forms humidified oxidant gas input stream 650 and dry oxidant gas output stream 750. Enthalpy wheel 300 operates by transferring sensible heat and latent heat contained in the water vapor of humidified output stream 700 to dry oxidant input stream 600, thereby forming humidified oxidant input stream 650. Enthalpy wheel 300 is rotationally driven and is formed of a material (e.g., acrylic fiber) which is chemically resistant to de-ionized water. The material is coated with zeolite, which acts as a water-selective molecular sieve. The mass of enthalpy wheel 300 transfers sensible heat from stream 700 to stream 600. The zeolite traps and transfers water, and therefore latent heat, from stream 700 to stream 600. Enthalpy wheels are commercially available from, for example, Engelhardt Corp., LaRoche Air Systems, Inc. and Emprise Corp.

The size of enthalpy wheel 300 is determined by operating fuel cell 200 at a flow rate of reactant gases in streams 650 and 800 which corresponds to a predetermined maximum flow rate that will be used during operation of fuel cell 200 and measuring the difference in the dew point between streams 650 and 700. Enthalpy wheel 300 should be large enough so that, at this maximum predetermined reactant gas flow rate, the difference between the dew point of stream 700 and the dew point of stream 650 is less than about 8°C (e.g., less than about 5°C or less than about 3°C).

An enthalpy wheel having a diameter of about 6 inches and a length of about 7.4 inches has been found to result in a dew point of 70°C for stream 700 and a dew point of 65°C for stream 650 when operating a fuel cell at a reactant gas flow rate through stream 650 of about 20 cubic

feet per minute. This reactant gas flow rate provides a fuel cell power output of about 7 kW. Using this enthalpy wheel results in the same dew points of 65°C and of 70°C for stream 650 and 700, respectively, when the fuel cell is
5 operated at a reactant gas flow rate of about 5 cubic feet per minute. This reactant gas flow rate provides a fuel cell power output of about 2 kW.

While the use of an enthalpy wheel as an enthalpy recovery device has been described, the invention is not
10 limited to the use of an enthalpy wheel. Other enthalpy recovery devices can be used, including, for example, a substantially gas impermeable, water permeable membrane, such as disclosed in GB 2,139,110, which is hereby incorporated by reference. These membranes operate by
15 flowing gas stream 700 on one side of the membrane and gas stream 600 on the other side of the membrane. The water vapor in stream 700, as well as the latent heat and sensible heat contained therein, passes through the membrane, but the membrane blocks substantially all of the other gases from
20 passing therethrough. The membranes are commercially available from, for example, Pall Corp. (e.g., flat sheet membranes), Isotronics Corp. (e.g., tube-like membrane dryers) and W.L. Gore & Associates (e.g., flat sheet membranes).

25 In some embodiments, a desiccant wheel or cassette can be used as the enthalpy recovery device. Generally, such a device is designed to be reactivated by heat (e.g., electric heat, steam heat or waste heat). The device turns relatively slowly (e.g., 0.33 revolutions per minute) and is
30 relatively heavily loaded with a desiccant material (e.g., compared to certain enthalpy wheels) that has a relatively high affinity for water vapor. Typically, the moisture content of such a device depends upon the relative humidity

of the surrounding air. One type of desiccant wheel or cassette uses an absorbent (e.g., lithium chloride) which can undergo a chemical change as it attracts and retains water vapor. Another type of desiccant wheel or cassette
5 uses an adsorbent having pores at its surface which can hold water vapor.

In certain embodiments, the enthalpy recovery device can be a sensible heat rotor. Generally, sensible heat rotors recovery primarily thermal heat (e.g., only thermal
10 heat). A sensible heat rotor can be used in combination with, for example, a desiccant wheel so that the sensible heat rotor can further reduce the temperature of humidified oxidant gas output stream 700 which can allow additional condensate to drop out of stream 700 (e.g., by first passing
15 stream 700 through a desiccant wheel then a sensible heat rotor).

Various combinations of enthalpy recovery devices can be used.

Fig. 2 shows an embodiment of fuel cell 200 designed
20 to catalyze the fuel cell reaction. Fuel cell 200 includes a cathode flow field plate 210, an anode flow field plate 220, a solid electrolyte 230, catalysts 240 and 250 and gas diffusion layers 260 and 270. As shown in Figs. 2 and 3, fuel cell 200 has an active area (i.e., an area where the
25 fuel cell reaction occurs) represented by area 232 of solid electrolyte 230. Active area 232 is defined by edges 234, 235, 236 and 237 and corresponds to the area of solid electrolyte 230 between gas diffusion layers 260 and 270.

Electrolyte 230 should be capable of allowing ions
30 to flow therethrough while providing a substantial resistance to the flow of electrons. Electrolyte 230 is a solid polymer (e.g., a solid polymer ion exchange membrane), such as a solid polymer proton exchange membrane (e.g., a

solid polymer containing sulfonic acid groups). Such membranes are commercially available from E.I. DuPont de Nemours Company (Wilmington, DE) under the trademark NAFION. Alternatively, electrolyte 230 can also be prepared from the commercial product GORE-SELECT, available from W.L. Gore & Associates (Elkton, MD).

Catalyst 240 can be formed of a material capable of interacting with molecular hydrogen to form protons and electrons. Examples of such materials include, for example, platinum, platinum alloys, and platinum dispersed on carbon black. The catalytic material can be dispersed in one or more solvents (e.g., isopropanol) to form a suspension. The suspension is then applied to the surfaces of solid electrolyte 230 that face gas diffusion layers 260 and 270, and the suspension is then dried. Alternatively, the suspension is applied to the surfaces of gas diffusion layers 260 and 270 that solid electrolyte 230, respectively, and the suspension is then dried. The method of preparing catalyst 240 may further include the use of heat and temperature to achieve bonding.

Catalyst 250 can be formed of a material capable of interacting with molecular oxygen, electrons and protons to form water. Examples of such materials include, for example, platinum, platinum alloys, and noble metals dispersed on carbon black. Catalyst 250 can be prepared as described above with respect to catalyst 240.

Gas diffusion layers 260 and 270 are formed of a material that is both gas and liquid permeable material so that the reactant gases (e.g., molecular hydrogen and molecular oxygen) and products (e.g., water) can pass therethrough. In addition, layers 260 and 270 should be electrically conductive so that electrons can flow from catalyst 240 to anode flow field plate 220 and from cathode

flow field plate 210 to catalyst 250. Such materials are formed by infusing a porous carbon black cloth or paper with a slurry of carbon black followed by sintering with TEFLON material.

5 Figs. 2 and 4 show an embodiment of cathode flow field plate 210 which is used to provide a flow path that allows the molecular oxygen to interact with catalyst 250. Cathode 210 has an inlet 212, an outlet 214 and open-faced channels 216 that define a flow path for an oxidant gas from
10 inlet 212 to outlet 214. A projection of active area 232 of solid electrolyte 230 onto cathode flow field plate 210 corresponds to the serpentine portion of open-faced channels 216. The flow path first intersects (i.e., projects onto) active area 232 at a region 217 of the flow path where the
15 oxidant gas passes over edge 234, and last intersects active area 232 at a region 218 of the flow path where the oxidant gas passes over edge 235. The net thermal flow direction of the cathode flow field plate flow path across active area 232 is shown by the arrow. Between entrance region 217 and
20 exit region 218, the molecular oxygen contained in the oxidant gas permeates gas diffusion layer 270 to interact with catalyst 250, electrons and protons to form water. The water can pass back through diffusion layer 270, enter the oxidant stream in channels 216, and exit fuel cell 200
25 through cathode flow field plate outlet 214.

Figs. 2 and 5 show an embodiment of anode 220 which is designed to provide a flow path for a fuel gas that allows the molecular hydrogen to interact with catalyst 240. Anode flow field plate 220 has an inlet 222, outlet 224 and
30 open-faced channels 226 that define a flow path for a fuel gas from inlet 222 to outlet 224. A projection of active area 232 of solid electrolyte 230 onto anode flow field plate 220 corresponds to the serpentine portion of open-

5 faced channels 226. The flow path first intersects active
area 232 on anode flow field plate 220 at a region 227 of
the flow path where the fuel gas passes over edge 235, and
last intersects active area 232 at a region 228 of the flow
10 path where the fuel gas passes over edge 234. The net
thermal flow direction of the anode flow field plate flow
path across active area 232 is shown by the arrow. Thus,
the net thermal flow direction of the anode flow field plate
flow path across active area 232 is antiparallel to the net
15 thermal flow direction of the cathode flow field plate flow
path across active area 232 (i.e., the net thermal flow of
oxidant gas across active area 232 is counter to the net
thermal flow of fuel gas across active area 232). Because
the temperature of fuel gas input stream 800 is higher than
20 the dew point of humidified oxidant gas input stream 650,
this arrangement of the cathode and anode flow field plate
flow paths reduces the tendency of the fuel stream to
increase the temperature of edge 234 of solid electrolyte
230, thereby reducing the tendency of edge 237 to dehydrate
25 due to the oxidant gas to absorbing water from edge 237.

 In some embodiments, cathode flow field plate 210
and anode flow field plate 220 can be arranged so that the
net thermal flow of the oxidant gas across active area 232
is not counter to the net thermal flow of fuel gas across
25 active area 232.

 Along the anode flow field plate flow path between
entrance region 227 and exit region 228, the molecular
hydrogen contained in the fuel gas permeates gas diffusion
layer 260 to interact with catalyst 240 to form protons and
30 electrons. The protons pass through solid electrolyte 230,
and the electrons pass are conducted through gas diffusion
layer 260 to anode flow field plate 220, ultimately flowing
through an external load to cathode flow field plate 210.

The heat produced during the fuel cell reaction is removed from fuel cell 200 by flowing a coolant through the fuel cell via a coolant flow field plate. Fig. 6 shows an embodiment of coolant flow field plate 530 having an inlet 532, an outlet 534 and open-faced channels 536 that define a flow path for coolant from inlet 532 to outlet 534. A projection of active area 232 of solid electrolyte 230 onto coolant flow field plate 530 corresponds to the serpentine portion of open-faced channels 536. The flow path first intersects active area 232 on coolant flow field plate 530 at a region 537 of the flow path where the coolant passes over edge 234, and last intersects active area 232 at a region 538 of the flow path where the coolant passes over edge 235. The net thermal flow direction of the anode flow field plate flow path across active area 232 is shown by the arrow. The flow field of coolant flow field plate 530 is generally parallel to the flow field for both cathode flow field plate 210 (i.e., the net thermal flow of oxidant gas across active area 232 is concurrent with the net thermal flow of coolant across active area 232). Thus, the first and last points of intersection with active area 232 of solid electrolyte 230 are substantially the same for the cathode flow field plate flow path and the coolant flow field plate flow path (i.e., sufficiently close so that region 217 is substantially the same temperature as region 537 and region 218 is substantially the same temperature as region 538 during operation of fuel cell 200 when the fuel cell reaction is occurring and coolant is flowing through coolant flow field plate 530). With this arrangement, the temperature of edge 234 of solid electrolyte 230 (i.e., the first portion of the cathode flow field plate flow path that intersects active area 232 of solid electrolyte 230) can be set so that it is less than or about the same as (e.g.,

within about 0.8°C, such as within about 0.5°C or within about 0.3°C of) the dew point of the oxidant gas at edge 237. This reduces the tendency for edge 237 to become dehydrated due to water absorption by the oxidant gas from edge 237. In addition, the net thermal flow direction of the coolant flow field plate flow path across active area 232 is parallel to the net thermal flow direction of the cathode flow field plate flow path across active area 232.

In some embodiments, cathode flow field plate 210 and coolant flow field plate 530 can be arranged so that the net thermal flow of the oxidant gas across active area 232 is not concurrent with the net thermal flow of coolant across active area 232.

Referring to Fig. 7, a coolant system 500 controls the mass flow rate and temperature of coolant flowing through coolant flow field plate 530 and thereby controls the temperature gradient across coolant flow field plate 530 from coolant flow field plate inlet 532 to coolant flow field plate outlet 534. Coolant system 500 includes a coolant input stream 510, coolant output stream 520, a variable speed fan 540, a pump (e.g., a constant speed pump or a variable speed pump) 550, a coolant stream input temperature sensor 560, a coolant stream output temperature sensor 565, an oxidant gas input stream dew point sensor 570, an oxidant gas output stream dew point sensor 575, and a feedback device 580.

Feedback device 580 is electrically connected to fan 540, pump 550 and sensors 560, 565, 570 and 575. Device 580 senses the dew point of streams 650 and 700 using sensors 570 and 575, respectively, and the temperature of streams 510 and 520 using sensors 560 and 565, respectively. Device 580 then sets the speed of fan 540 and/or the speed of pump 550 to control the temperature and/or mass flow rate of the

coolant (e.g., de-ionized water or a low freezing temperature fluid, such as a hydrocarbon oil or a silicone oil) flowing in stream 510 so that the dew point of stream 650 is greater than or about the same as (e.g., within about 0.8°C, such as within about 0.5°C or within about 0.3°C of) the temperature of stream 510, and the dew point of stream 700 is about the same as the temperature of stream 520 (e.g., within about 0.8°C, such as within about 0.5°C or within about 0.3°C). This results in the temperature differential between streams 510 and 520 being about the same as (e.g., within about 0.5°C, such as within about 0.2°C or within about 0.1°C of) the difference in the dew points of streams 650 and 700, which optimizes the efficiency with which enthalpy wheel 300 transfers water from stream 700 to stream 600.

Although certain embodiments and arrangements of cathode flow field plate 210, anode flow field plate 220 and coolant flow field plate 530 have been described herein, other embodiments and arrangements of these flow field plates can also be used so long as the temperature matching properties described above are achieved. For example, other embodiments are disclosed in commonly assigned U.S. Patent Application Serial No. 09/168,232, entitled "Fuel Cell Assembly Unit for Promoting Fluid Service and Design Flexibility", which is hereby incorporated by reference.

Moreover, while a fuel cell system containing a single fuel cell has been described herein, the fuel cell system is not limited to such systems. Rather, the fuel cell system can include a plurality of fuel cells. Typically, the fuel cells in such systems are arranged in series by having the back side of a cathode flow field plate in one fuel cell serve as the anode flow field plate in the next fuel cell in the series arrangement. A plurality of

coolant flow field plates can also be used in these systems. Examples of fuel cell systems having a plurality of fuel cells and coolant flow field plates are described in U.S. Patent Application Serial No. 09/168,232.

5 While certain embodiments of the invention, as well as their principals of operation, have been disclosed herein, the invention is not limited to these embodiments or these principals of operation. Other embodiments are in the claims.

10 What is claimed is:

Claims

1. A fuel cell system, comprising:
a fuel cell, comprising:
a cathode flow field plate having an inlet, an
5 outlet, and a flow path from the cathode flow field plate
inlet to the cathode flow field plate outlet;
an anode flow field plate;
a coolant flow field plate having an inlet, an
outlet, and a flow path from the coolant flow field plate
10 inlet to the coolant flow field plate outlet; and
a solid electrolyte between the cathode and
anode flow field plates, the solid electrolyte having an
active area; and
an enthalpy recovery device having a first side and
15 a second side different than the first side, the first side
of the enthalpy recovery device being in fluid communication
with the cathode flow field plate outlet, and the second
side of the enthalpy recovery device being in fluid
communication with the cathode flow field plate inlet,
20 wherein a first region of the cathode flow field
plate flow path intersects the solid electrolyte active area
at a region closest to the cathode flow field plate inlet
along the cathode flow field plate flow path, and a first
region of the coolant flow field plate flow path intersects
25 the solid electrolyte active area at a region closest to the
coolant flow field plate inlet along the coolant flow field
plate flow path, the first region of the coolant flow field
plate flow path being substantially the same as the first
region of the cathode flow field plate flow path.

2. The fuel cell of claim 1, wherein the cathode flow field plate flow path is concurrent with the coolant flow field plate flow path.
3. The fuel cell system of claim 1, further comprising
5 a coolant system, comprising:
a feedback device; and
a variable speed pump having a pump speed, a pump inlet and a pump outlet in fluid communication with the pump inlet, the pump inlet being in fluid communication with the
10 coolant flow field plate outlet, and the pump outlet being in fluid communication with the coolant flow field plate inlet,
wherein the feedback device is in electrical communication with the variable speed pump to control the
15 pump speed.
4. The fuel cell system of claim 3, wherein the coolant system further comprises:
a first temperature sensor in thermal communication with the coolant flow field plate inlet and in electrical
20 communication with the feedback device; and
a second temperature sensor in thermal communication with the coolant flow field plate outlet and in electrical communication with the feedback device.
5. The fuel cell device of claim 4, wherein the coolant
25 system further comprises:
a third temperature sensor in thermal communication with the cathode flow field plate inlet and in electrical communication with the feedback device; and

a fourth temperature sensor in thermal communication with the cathode flow field plate outlet and in electrical communication with the feedback device.

6. The fuel cell system of claim 5, wherein the coolant
5 system further comprises a variable speed fan having a fan speed, the variable speed fan being in electrical communication with the feedback device so that the feedback device controls the fan speed.
7. The fuel cell system of claim 1, further comprising
10 a liquid water separator having a separator inlet, a first separator outlet and a second separator outlet different than the first separator outlet, the separator inlet being in fluid communication with the cathode flow field plate outlet, the first separator outlet being in fluid
15 communication with the first side of the enthalpy recovery device, and the second separator outlet being capable of transporting liquid water from the liquid water separator.
8. The fuel cell system of claim 1, wherein the enthalpy recovery device comprises an enthalpy wheel.
- 20 9. The fuel cell system of claim 1, wherein the enthalpy recovery device comprises a membrane.
10. The fuel cell system of claim 1, wherein the anode flow field plate has an inlet, an outlet, and a flow path from the anode flow field plate inlet to the anode flow
25 field plate outlet, and
wherein a first region of the anode flow field plate flow path intersects the solid electrolyte active area at a region closest to the anode flow field plate inlet along the

anode flow field plate flow path, a second region of the cathode flow field plate flow path intersects the solid electrolyte active area at a region closest to the cathode flow field plate outlet along the cathode flow field plate flow path, and the first region of the anode flow field plate flow path being substantially the same as the second region of the cathode flow field plate flow path.

11. The fuel cell system of claim 10, wherein the anode flow field plate flow path has a net thermal flow with a direction and the cathode flow field plate flow path has a net thermal flow with a direction antiparallel to the net thermal flow direction of the anode flow field plate flow path.

12. The fuel cell system of claim 11, wherein the cathode flow field plate flow path is concurrent with the coolant flow field plate flow path.

13. The fuel cell of claim 1, wherein the solid electrolyte comprises a proton exchange membrane.

14. A method of operating a fuel cell system, comprising:

introducing an oxidant gas stream into the fuel cell, the oxidant gas stream having a dew point at introduction into the fuel cell;

introducing a coolant stream into the fuel cell, the coolant stream having a temperature at introduction into the fuel cell that is about the same as the dew point of the oxidant gas stream;

flowing the oxidant gas stream through the fuel cell along an oxidant gas stream flow path to an oxidant gas stream outlet;

5 flowing the coolant stream through the fuel cell along a coolant stream flow path;

reacting molecular oxygen contained in the oxidant gas stream with molecular hydrogen in the fuel cell to form a humidified oxidant gas output stream;

10 outputting the humidified oxidant gas output stream from the oxidant gas stream outlet; and

transferring water vapor from the humidified oxidant gas output stream to a dry oxidant gas stream to form a humidified oxidant gas input stream.

15 15. The method of claim 14, further comprising introducing the humidified oxidant gas input stream to the fuel cell.

20 16. The method of claim 15, wherein the humidified oxidant gas input stream has a dew point at introduction into the fuel cell that is about the same as the temperature of the coolant stream at introduction into the fuel cell.

17. The method of claim 14, wherein the water vapor is transferred from the humidified oxidant gas output stream to the dry oxidant gas stream by flowing the humidified oxidant output gas stream through an enthalpy recovery device.

25 18. The method of claim 14, further comprising outputting the coolant stream from the fuel cell, the coolant stream having a temperature at output from the fuel cell that is about the same as a temperature of the

humidified oxidant output gas stream at output from the fuel cell.

19. The method of claim 18, further comprising introducing the humidified oxidant gas input stream to the
5 fuel cell, the humidified oxidant gas input stream having a temperature at introduction into the fuel cell that is about the same as the temperature of the coolant stream at introduction into the fuel cell.

20. The method of claim 14, further comprising:
10 outputting the coolant stream from the fuel cell;
and
adjusting a mass flow rate of the coolant stream to set a difference between the coolant stream temperature at introduction into the fuel cell and a coolant stream
15 temperature at output from the fuel cell.

21. The method of claim 20, wherein the coolant stream temperature at output from the fuel cell is about the same as a temperature of the humidified oxidant gas output stream at output from the fuel cell.

20 22. A method of operating a fuel cell system including a fuel cell having a solid electrolyte with an active area, the method comprising:
flowing an oxidant gas stream through the fuel cell
along an oxidant gas stream flow path having a first region
25 that intersects the solid electrolyte active area at a region closest to a cathode inlet along the cathode flow path, the oxidant gas stream having a dew point at the first region of the oxidant gas stream flow path;

- flowing a coolant through the fuel cell along a coolant flow path having a first region that intersects the solid electrolyte active area at a region closest to the coolant inlet along a coolant flow path, the coolant having
- 5 a temperature at the first region of the coolant flow path that is about the same as the dew point of the oxidant gas stream at the first region of the oxidant gas stream flow path;
- outputting the oxidant gas stream from the fuel
- 10 cell; and
- transferring water vapor from the oxidant gas output stream to a dry oxidant gas stream to form a humidified oxidant gas stream input stream.
23. The method of claim 22, wherein the water vapor is
- 15 transferred from the oxidant gas output stream to the dry oxidant gas stream by flowing the humidified oxidant gas output stream through an enthalpy recovery device.
24. The method of claim 22, further comprising introducing the oxidant gas input stream into the fuel cell.
- 20 25. The method of claim 24, wherein a dew point of the oxidant gas input stream at introduction into the fuel cell is about the same as the temperature of the coolant at the first region of the coolant flow path.
26. The method of claim 22, further comprising
- 25 outputting the coolant from the fuel cell, the coolant having a temperature at output that is about the same as the dew point of the oxidant gas stream upon output from the fuel cell.

27. The method of claim 26, further comprising adjusting a mass flow rate of the coolant stream to set a difference between the coolant stream temperature at introduction into the fuel cell and a coolant stream temperature at output
5 from the fuel cell.
28. The method of claim 27, wherein the coolant stream temperature at output from the fuel cell is about the same as a temperature of the humidified oxidant gas output stream at output from the fuel cell.
- 10 29. The method of claim 22, further comprising:
outputting the coolant from the fuel cell; and
adjusting a mass flow rate of the coolant stream to set a difference between the coolant stream temperature at introduction into the fuel cell and a coolant stream
15 temperature at output from the fuel cell.
30. The method of claim 29, wherein the coolant stream temperature at output from the fuel cell is about the same as a temperature of the humidified oxidant gas output stream at output from the fuel cell.
- 20 31. The method of claim 22, wherein the solid electrolyte comprises a proton exchange membrane.

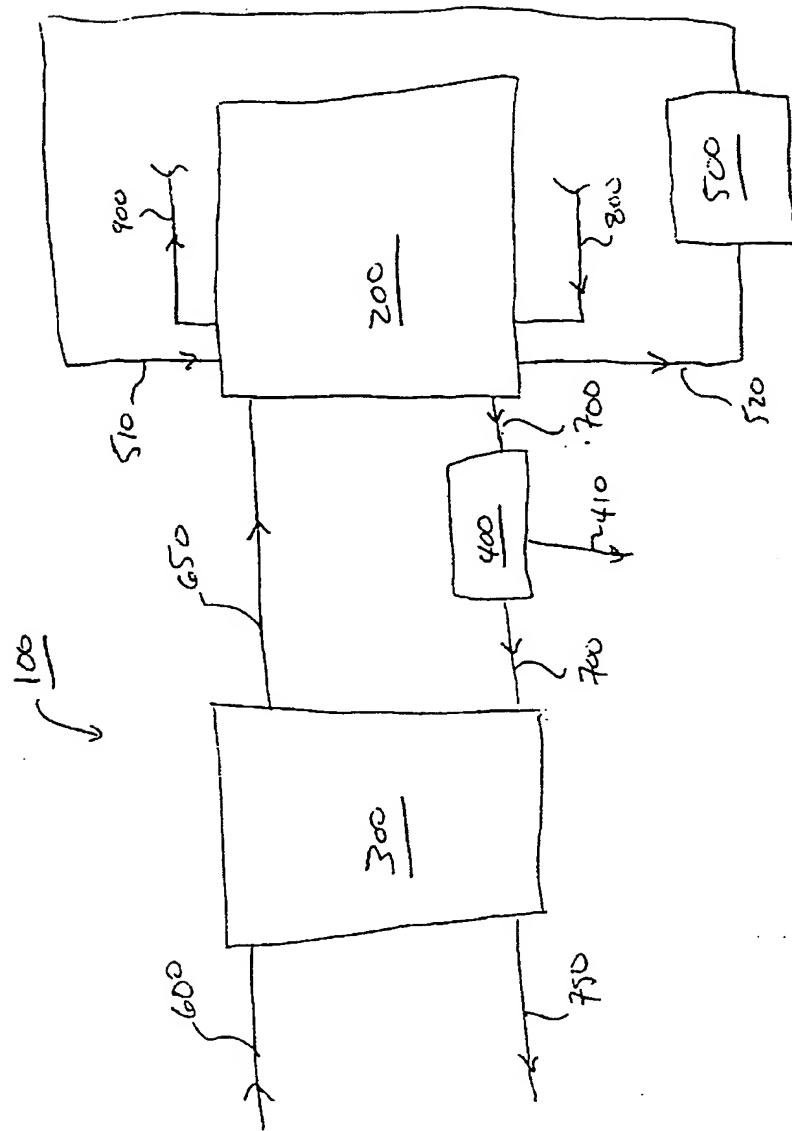


FIG. 1

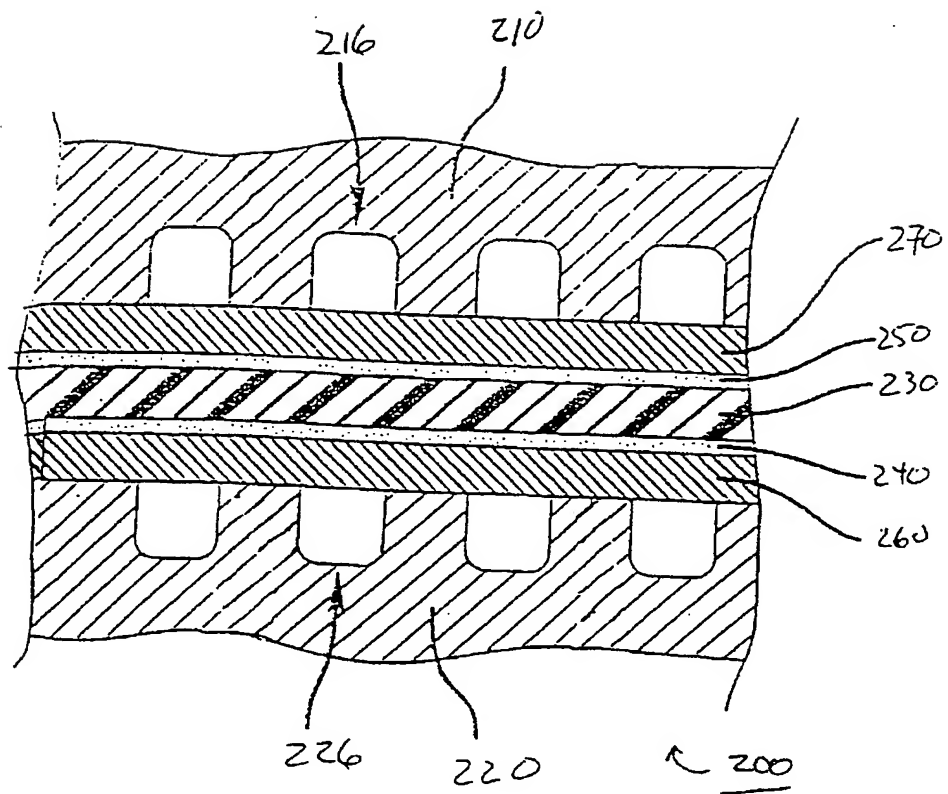


FIG. 2

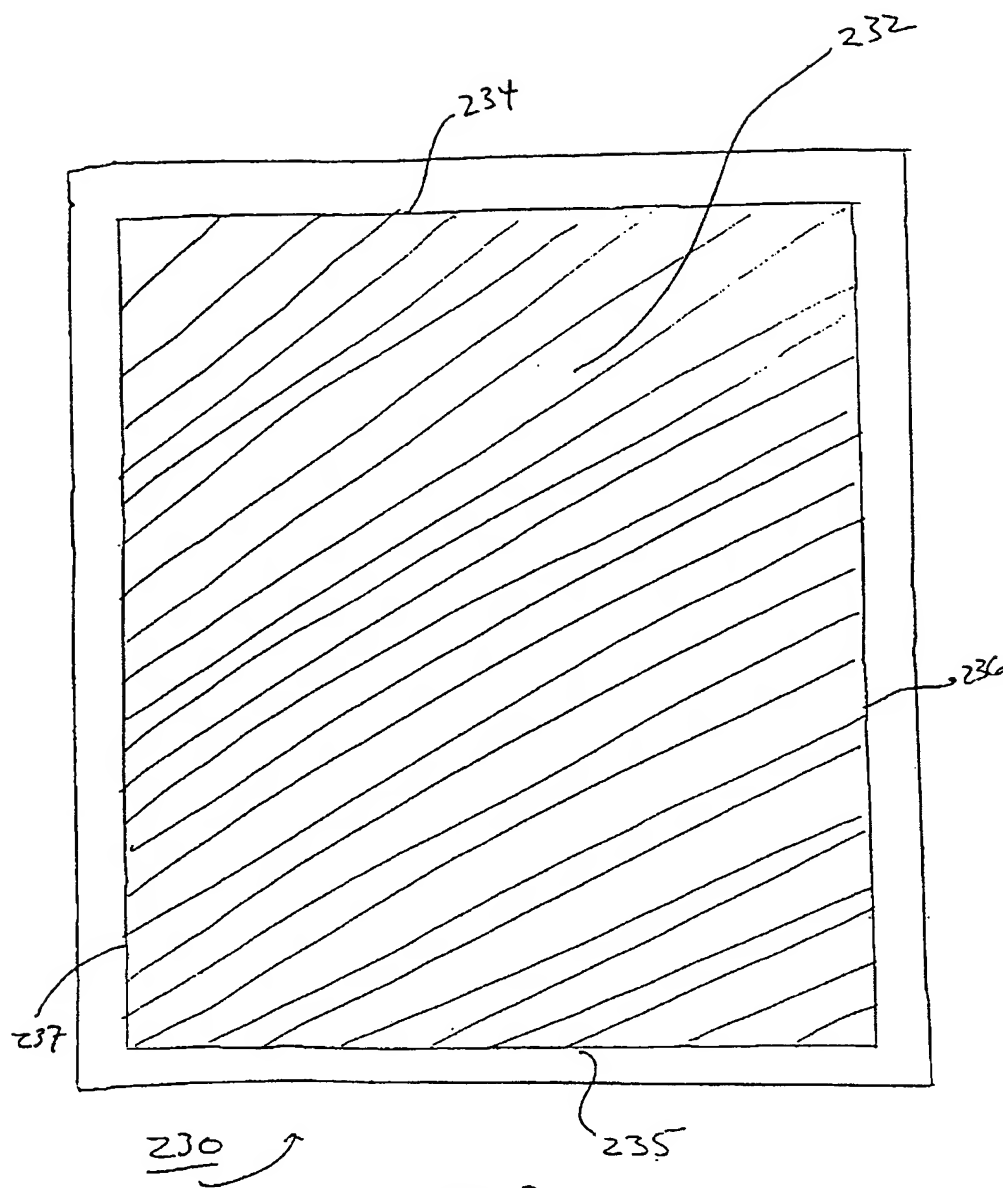


FIG. 3

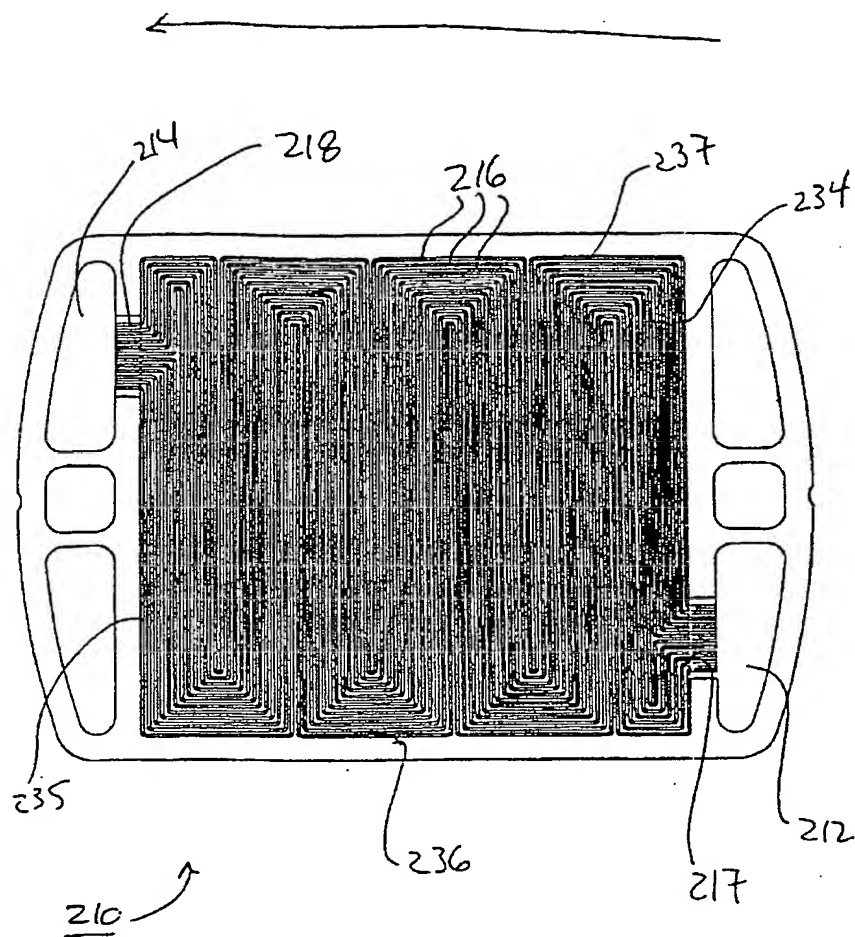


FIG. 4

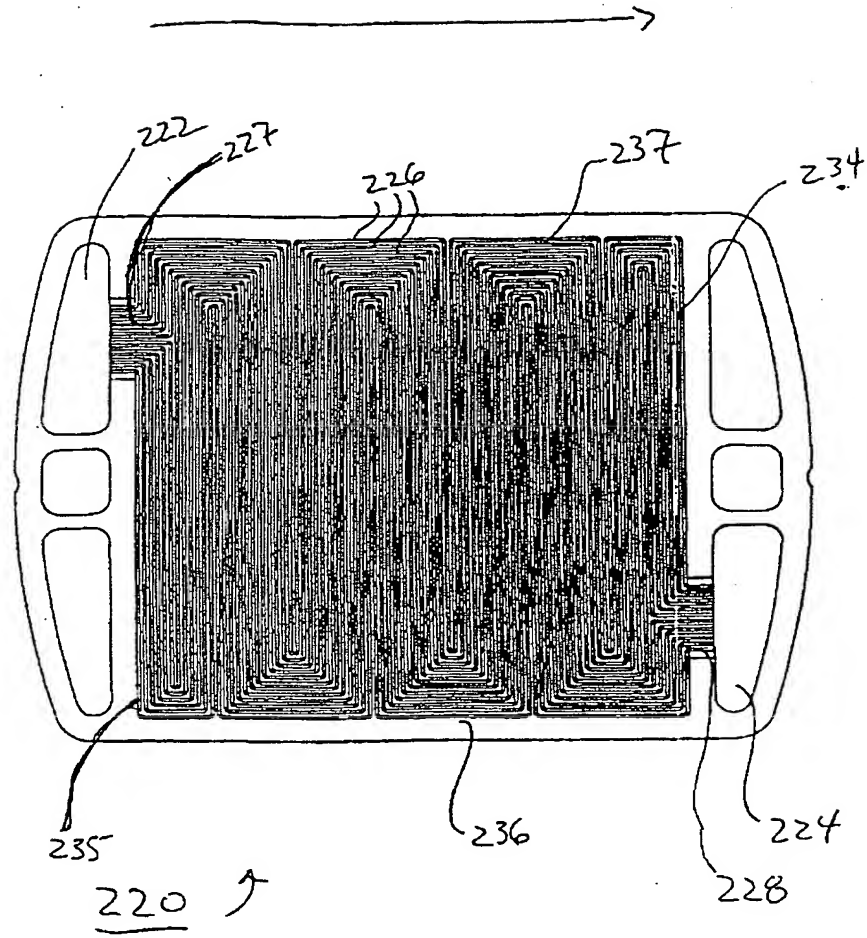


FIG. 5

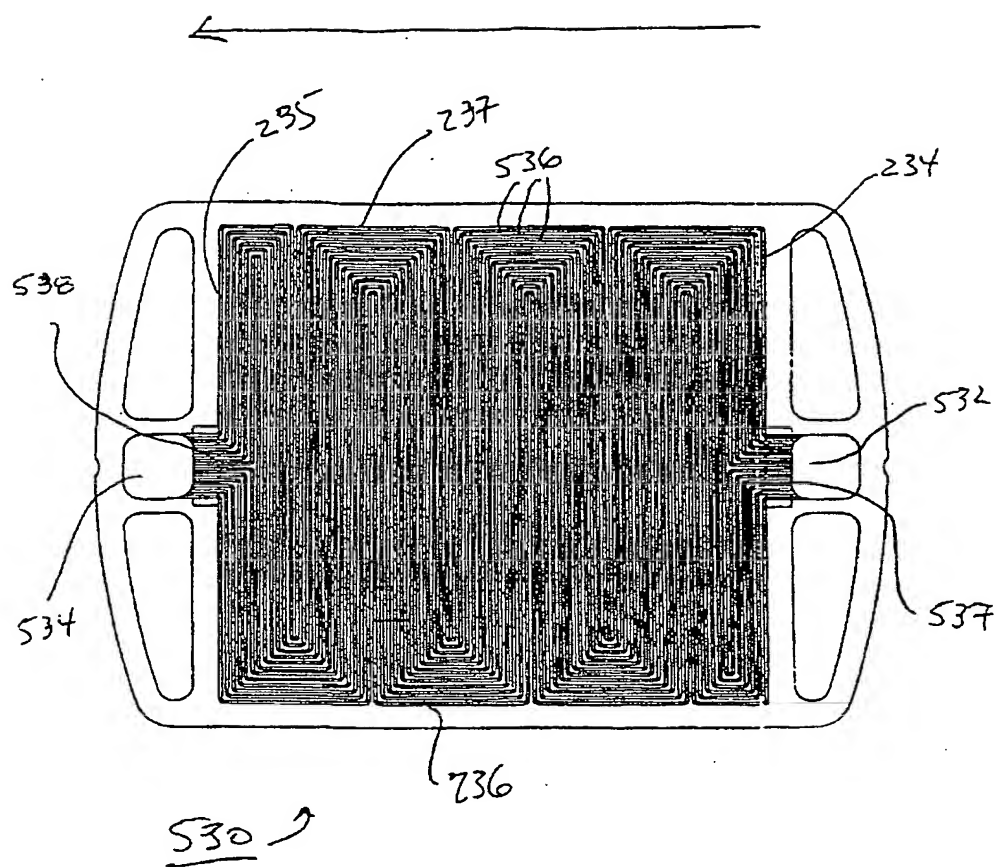
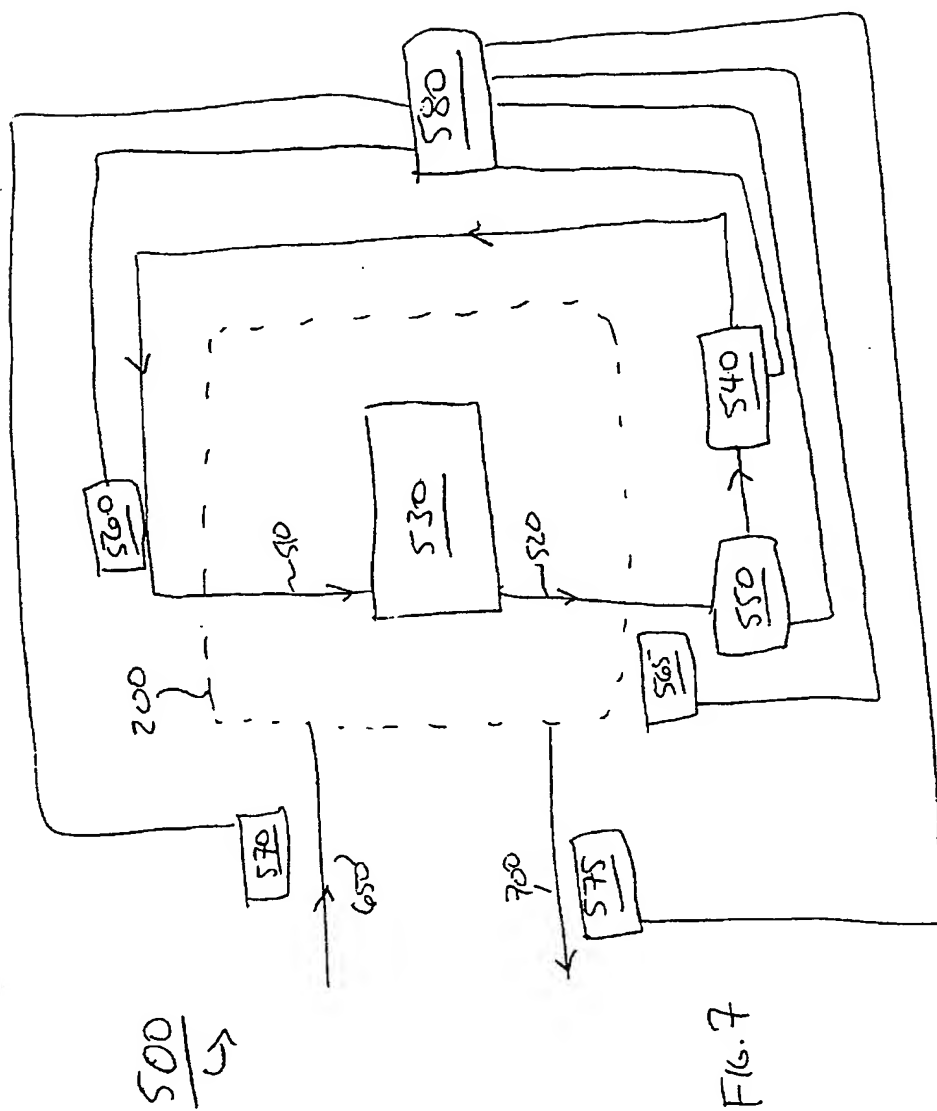


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/22295**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(7) :H01M 8/04

US CL :429/13, 26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 429/13, 24, 26, 34

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST: Uspat and Derwent

search terms: fuel adj cell, dew adj point

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, P	US 6,013,385 A (DUBOSE) 11 January 2000, col. 5, line 32-col. 6, line 28, figure 2.	1, 2, 7-13
Y, P	US 6,080,502 A (NÖLSCHER et al) 27 June 2000, col. 8, lines 4-66, figure 3.	1, 2, 7-13
A	US 5,840,438 A (JOHNSON et al) 24 November 1998, col. 7, lines 18-34, figure 3.	1-13
A, P	US 6,042,956 A (LENEL) 28 March 2000, col. 4, lines 49-58.	14-31
A	US 4,533,607 A (SEDERQUIST) 06 August 1985, col. 2, lines 14-26.	14-31
A	US 5,382,478 A (CHOW et al) 17 January 1995, col. 9, lines 1-66, figures 9A, 9B, 10A and 10B.	1-13

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

13 OCTOBER 2000

Date of mailing of the international search report

08 JAN 2001

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